HYDRAULICS

Hydraulics

- Teaching Objectives
  - Learn basic concepts
    - Water properties
    - Open channel flow
    - Culvert (or Pipe) flow
    - Variation in hydraulic conditions
    - Temperature and ice effects
    - Flow measurements

Hydraulics Definition

- **Wikipedia: Hydraulics is a topic in applied science and engineering dealing with the mechanical properties of liquids. Fluid mechanics provides the theoretical foundation for hydraulics, which focuses on the engineering uses of fluid properties.**

- **From Elementary Fluid Mechanics, Vennard and Street, 1975.**

  “Because of the conflict between theory and experiment, two schools of thought arose in the treatment of fluid mechanics, one dealing with the theoretical and the other with the practical aspects of fluid flow. In a sense, these two schools of thought have persisted to the present day, resulting in the mathematical field of hydrodynamics and the practical science of hydraulics.”

ESCRIPTION OF HYDRAULICS SECTION, St. Paul District

esponsible for hydraulic engineering associated with the planning, design, onstruction, operation, and maintenance for various civil works water resources rograms and projects.

he water resources areas covered include navigation, flood risk management, cosystem restoration, dam and levee safety, bank stabilization, flood econnaissance…….

he work includes:

modeling and design for levees, bank stabilization, channel improvements, inte flood control, habitat projects, and hydraulic structures

collecting and analyzing hydraulic and sediment transport data

ice reconnaissance and data collection

reconnaissance and support for flood emergencies

support to periodic inspections at locks and dams

wetlands permit reviews

dredge material management

coastal engineering

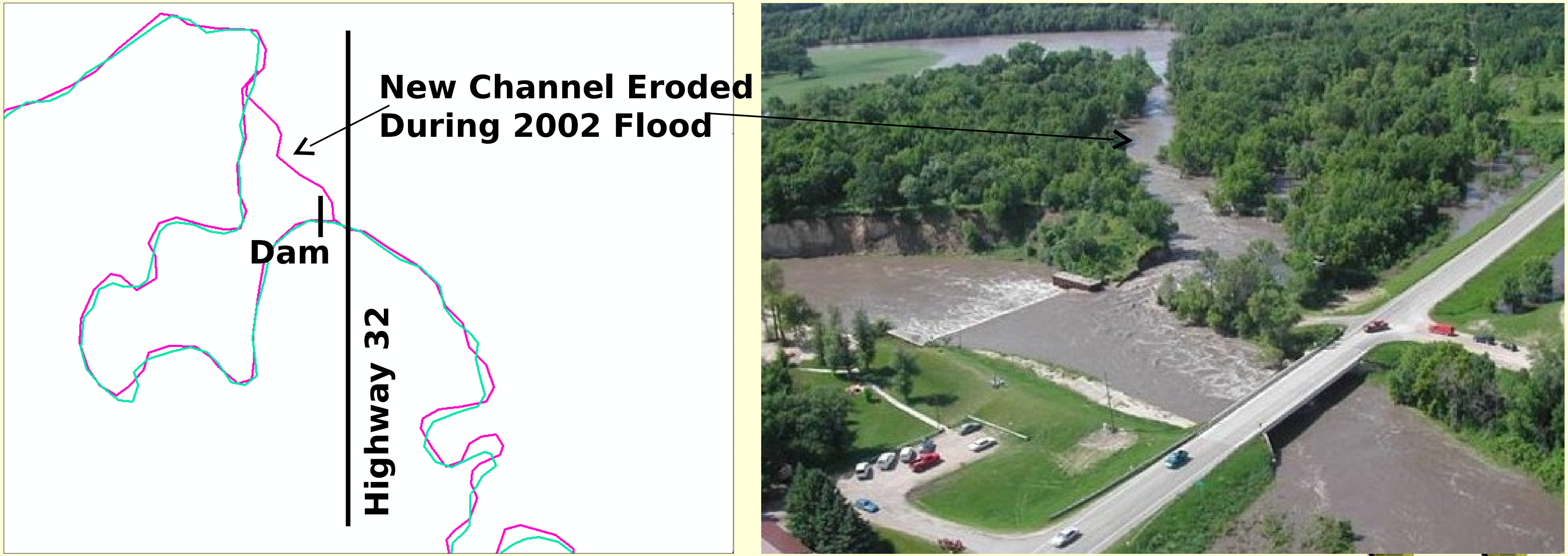
agency technical reviews

Water Properties

- Heavy - 1 cubic foot weighs 62.4 lbs
  - Gasoline weighs 42.5 lbs/ft3
  - Rock weighs 110 lbs/ft3
  - Concrete weighs 165 lbs/ft3
  - Wood: White Oak = 48 lbs/ft3
  - White Pine = 26 lbs/ft3
  - Temperature Affects: Important in lakes and reservoirs
- Why does something float?
- The laws of buoyancy (Archimedes' Principle, 250 BC) and floatation are usually stated:
  - A body immersed in a fluid is buoyed up by a force equal to the weight of fluid displaced
  - A floating body displaces its own weight of the liquid in which it floats

Water Properties

- Flows from high energy to lower energy zones
- Follows the path of least resistance



Water Properties

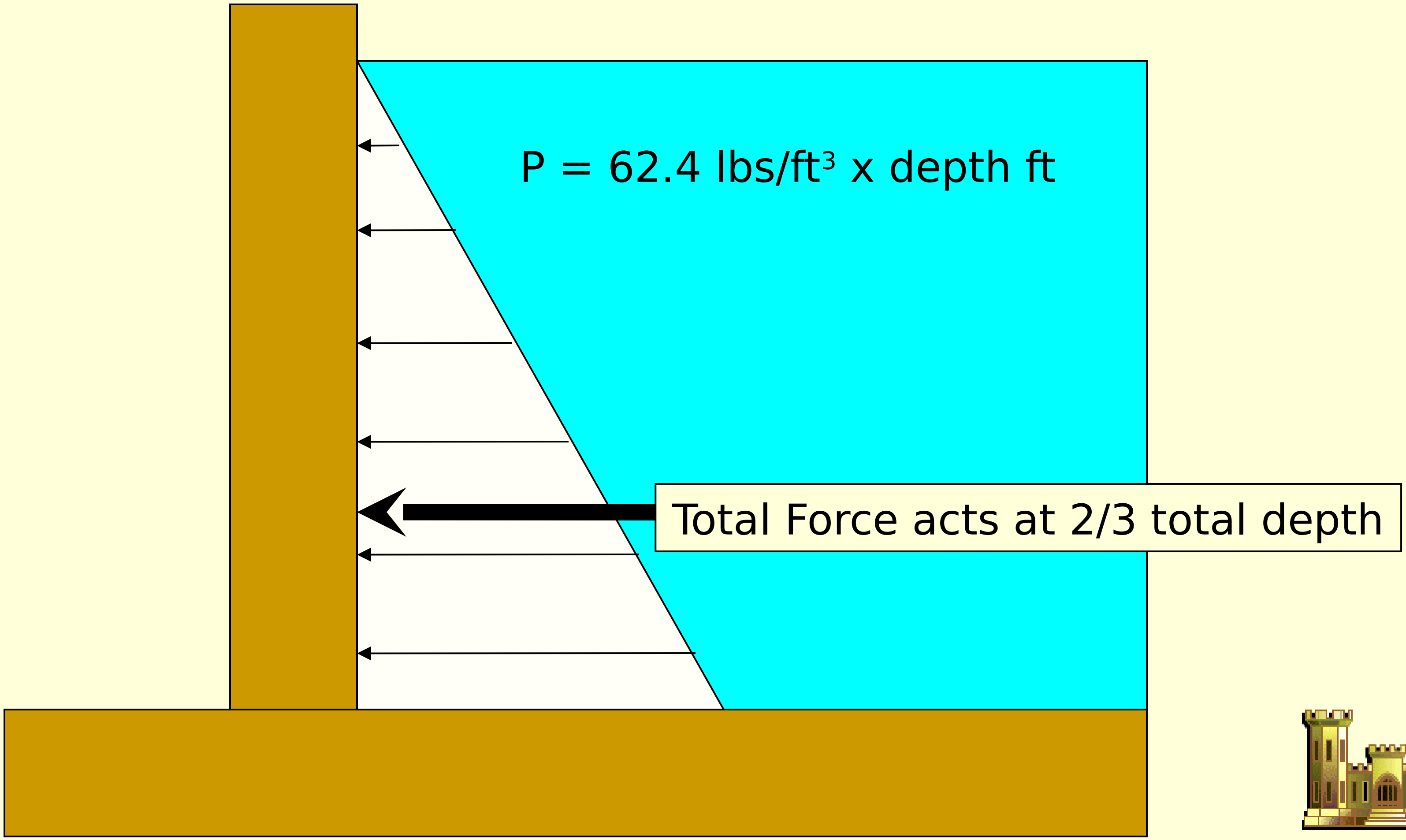
- Water Seeks its Own level
  - If it’s at elevation 100 on one side of a dam or levee, it wants to be the same elevation on the other side.
- Incompressible- So It Transmits Energy Well
- Liquid at normal temperature
- Heating to 212 °F (boiling point) raises the vapor pressure to atmospheric pressure and liquid turns to gas
- Lowering the pressure (for instance in a pipe or on a spinning propeller) can cause gas formation at lower temperatures
  - Cavitation: Low pressure conditions results in liquid to gas and then collapse back to liquid which plucks metal off turbine blades and concrete off spillways

Water Properties

- Density doesn't change significantly with ambient temperature range.
  - 1.9385 slugs/ft3 at 32 °F
  - 1.9388 slugs/ft3 at 40 °F (water is heaviest)
  - 1.9348 slugs/ft3 at 70 °F (0.2% lighter than at 40 °F)
- This means we can usually ignore density changes in flowing rivers because of mixing
- But in lakes these slight density differences result in thermal stratification

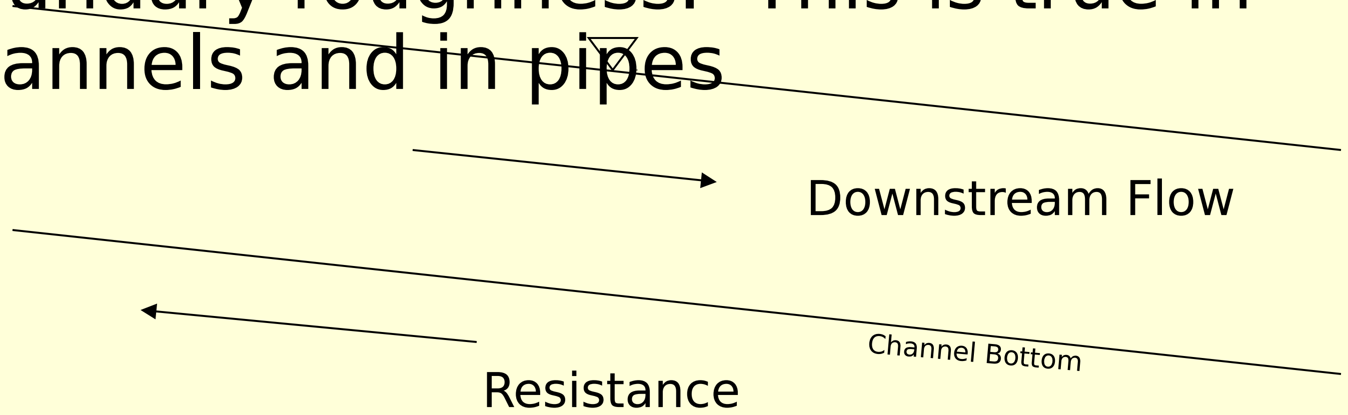
Water at Rest

- Pressure (P) Increases with Depth



Water in Motion

- Water moves from higher to lower energy
  - Gravity (or downhill) flow
  - Pumps can be used to increase the energy levels to move water to a higher level or to get it over a barrier
- The flow of water is resisted by the boundary roughness. This is true in channels and in pipes

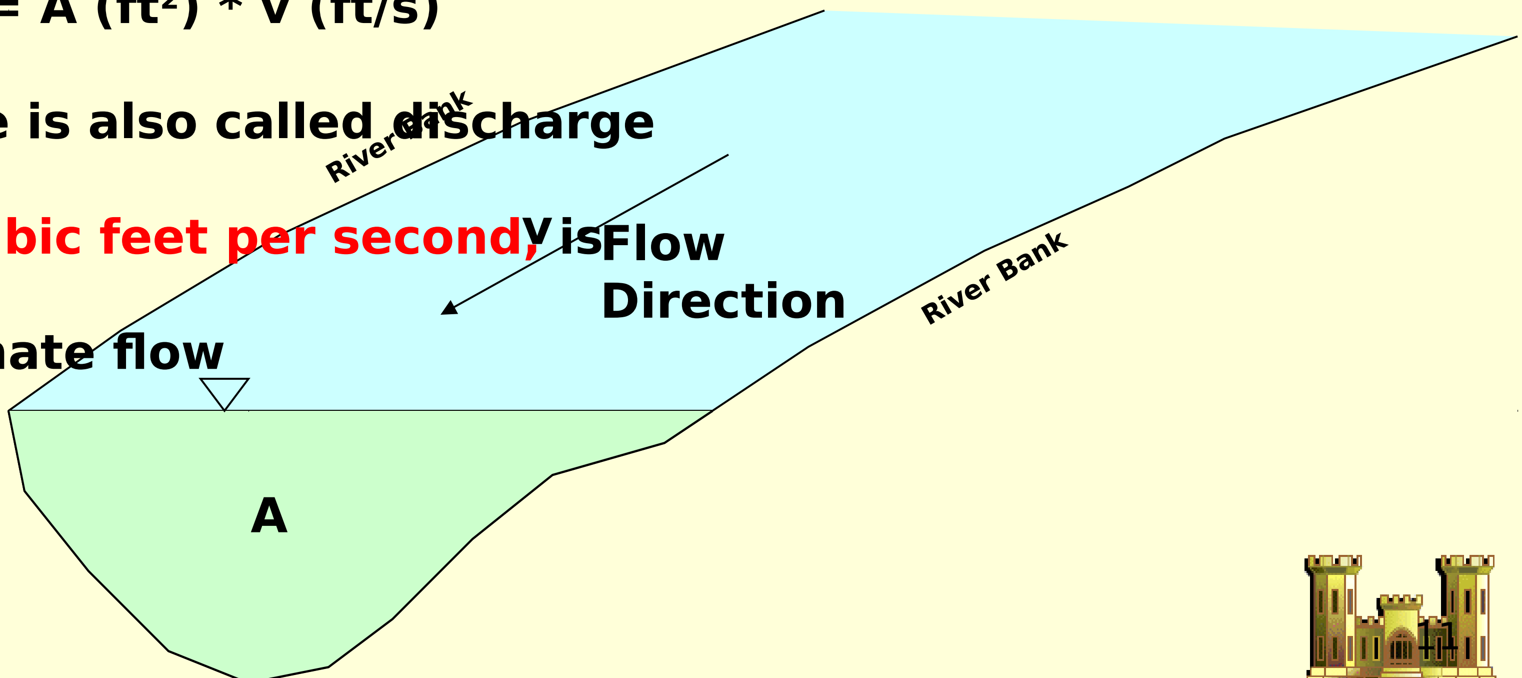


Water in Motion

The flow rate (Q) of water moving past a cross section is equal to the area (A) of the cross section multiplied by the velocity (v)

$Q\ (ft^3/s) = A\ (ft^2) * v\ (ft/s)$

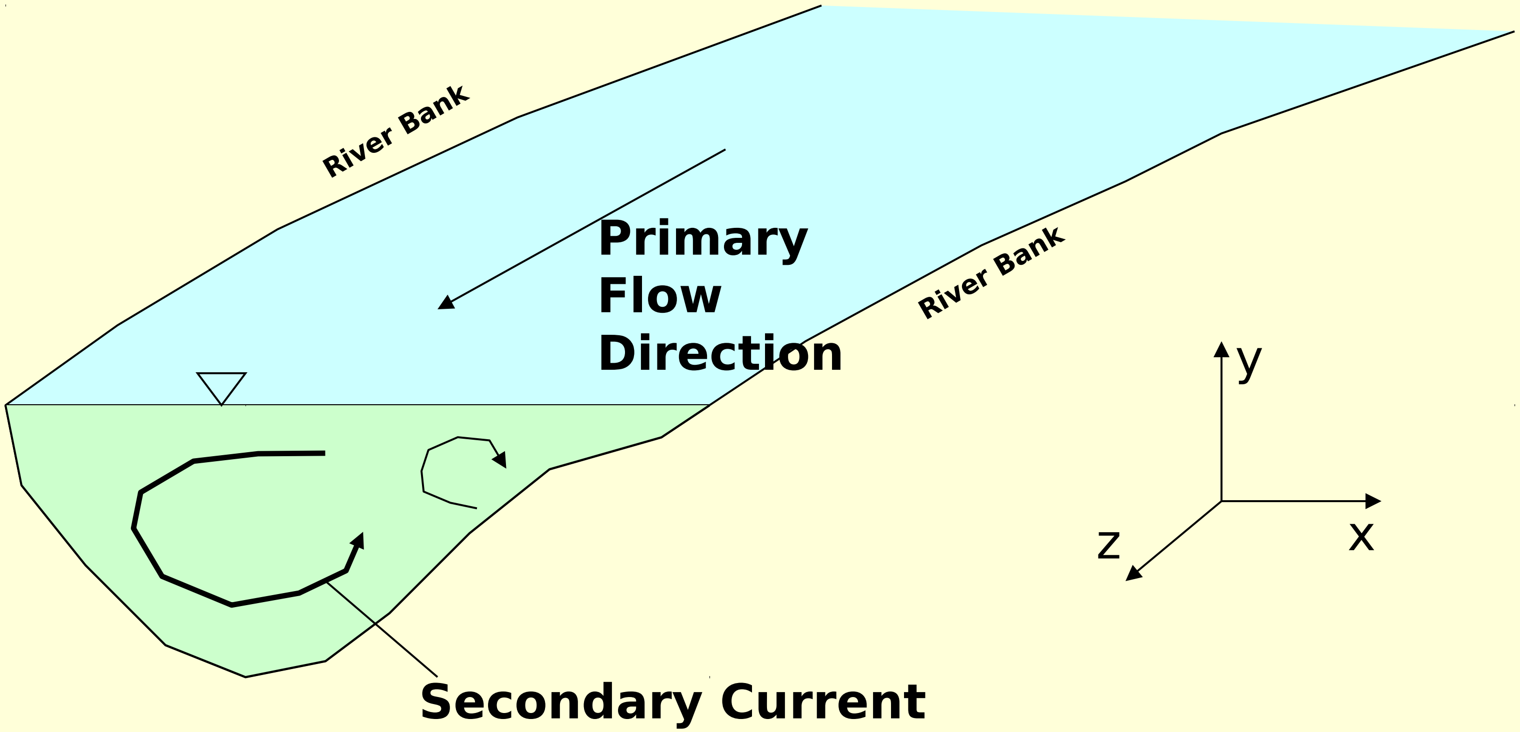
Flow rate is also called discharge and cfs, or cubic feet per second, is used to designate flow



Ways to describe water in motion

- The next few images attempt to define common terms that H&H people use when describing the movement of water.
- In a multi-discipline team setting you don’t need to be an expert in H&H, but you should understand some of the lingo.

One-, Two-, and Three-Dimensional Flows



Truth is that when water is flowing it is almost always 3-dimensional.
But that is difficult to quantify.
So we like to simplify, if we can, to 2-dimensional or 1-dimensional
in our descriptions, analysis, and modeling.

One-, Two-, and Three-Dimensional Flows

- When planners talk to hydraulic modelers they will hear the terms 1-D, 2-D, 3-D flow and models.
  - In a one-dimensional flow, the change of fluid variables (velocity, temperature, etc.) in one direction dominates over the change in the other two directions.
  - In two- and three-dimensional flows, the change in fluid variables is important in multiple directions.
  - Coefficients, model calibration, and past experience are used to account for simplifying assumptions.

Change of Flow with Respect to Time

- no change: steady
- changing: unsteady

Steady Flow Example

- Release at a spillway notch with a constant headwater
- Q = constant

Unsteady Flow Example

- Missouri River Flow hydrograph at Decatur
- Q v

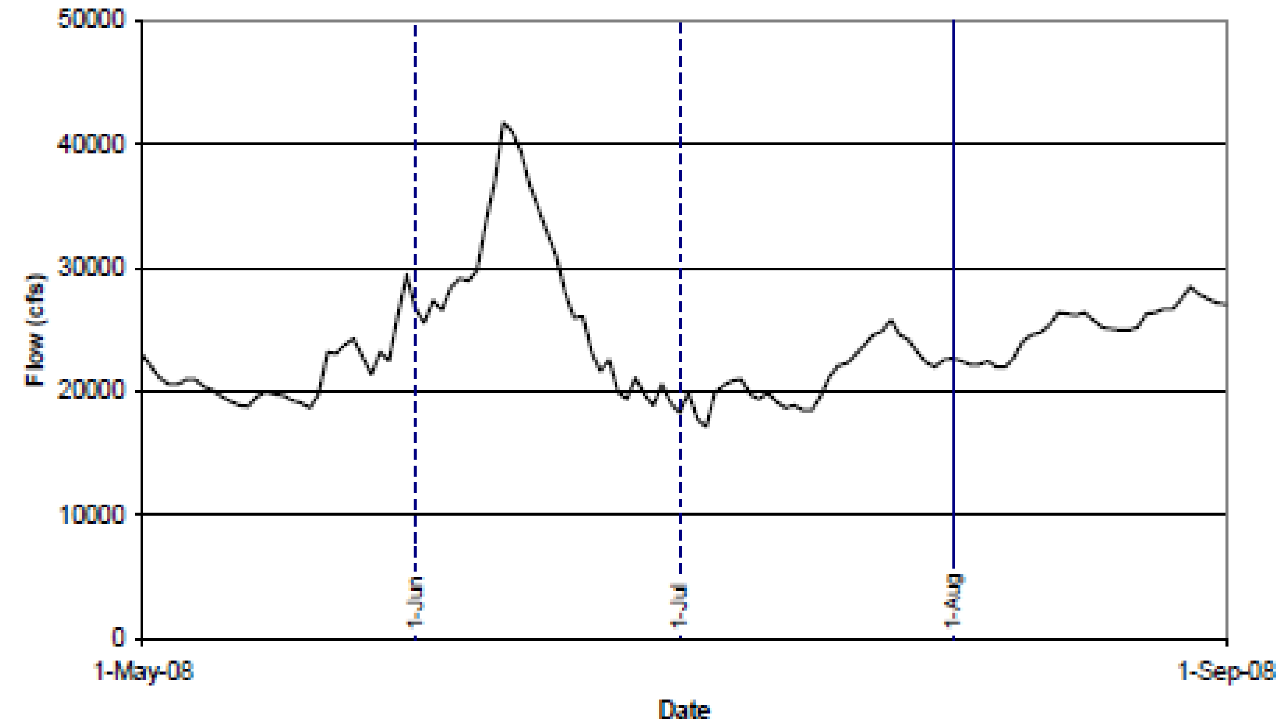
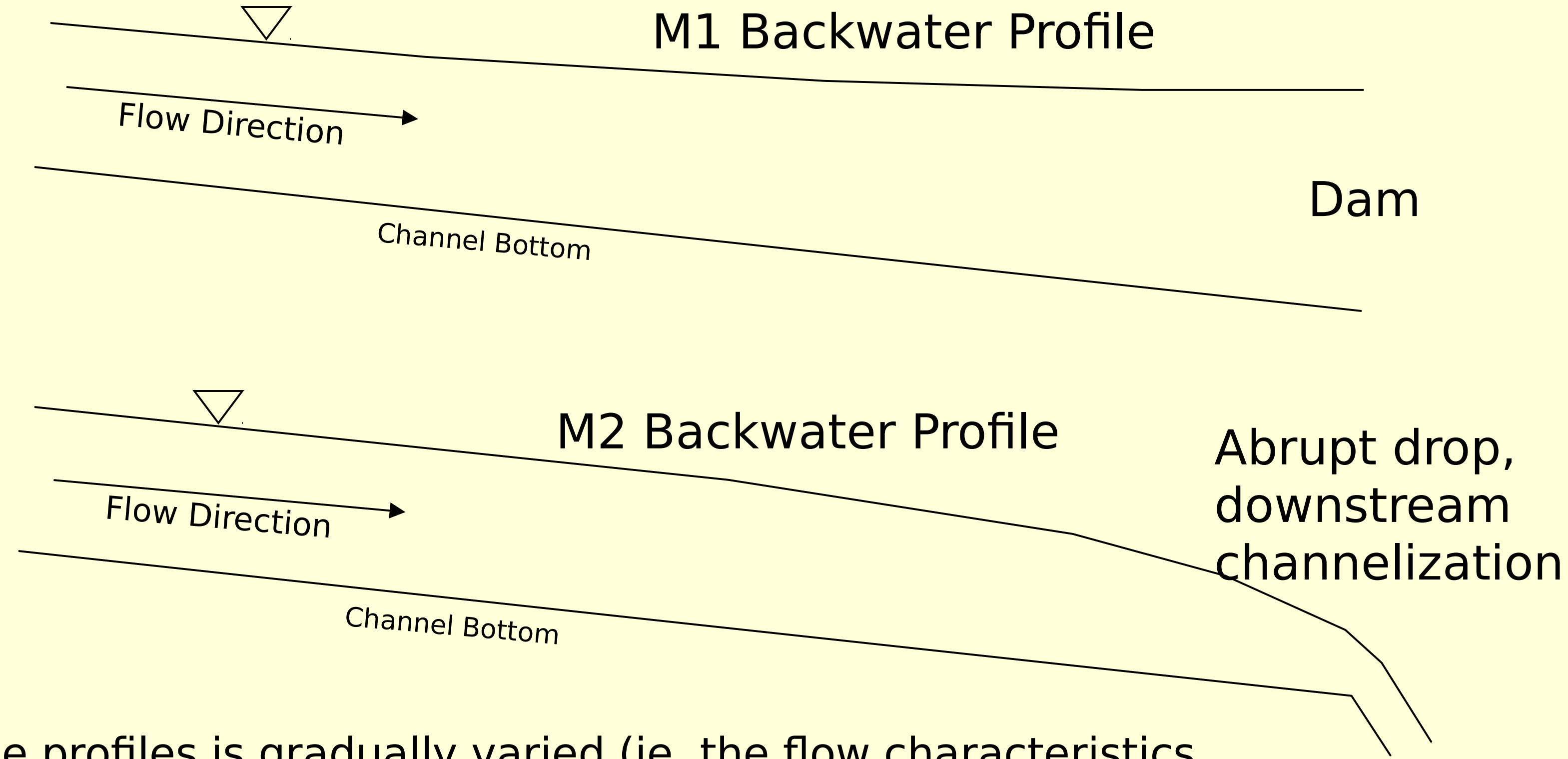


Figure 31: Missouri River Daily Flow at Decatur, May – Aug 2008

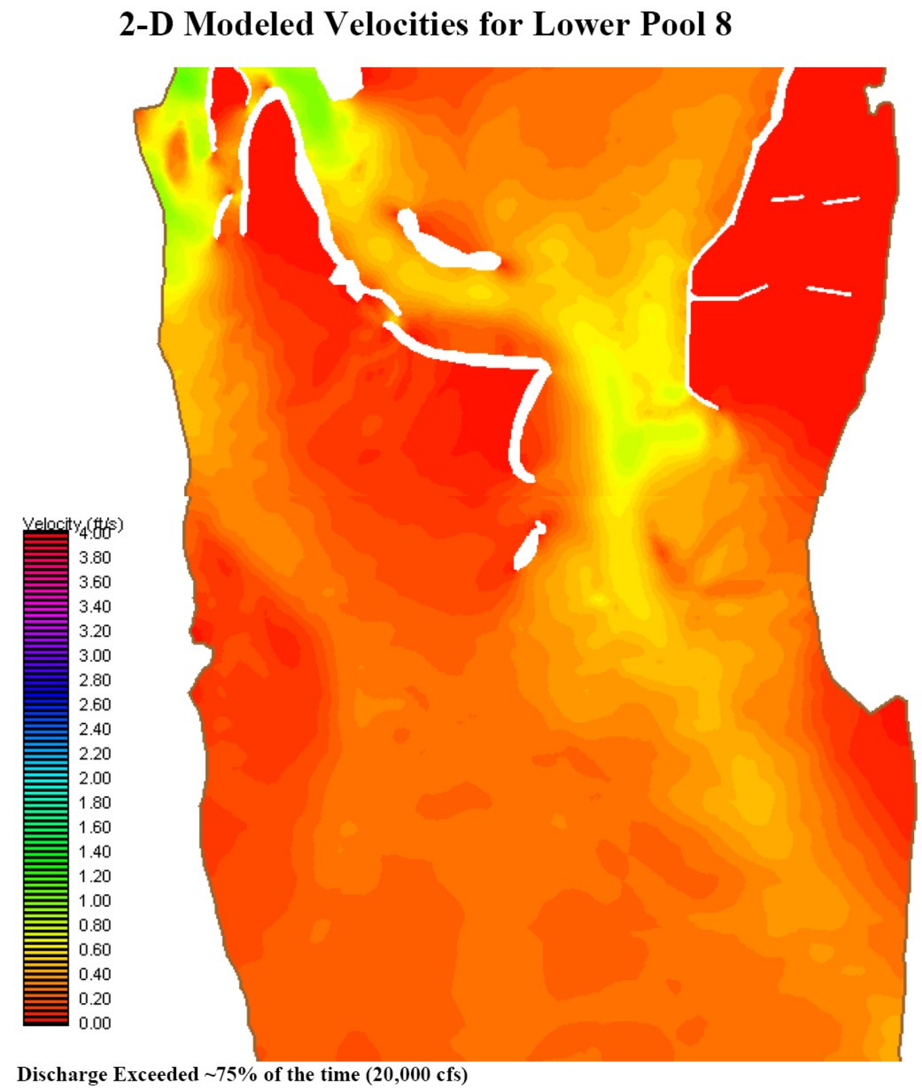
Change of Flow Conditions with Respect to Spatial Position?

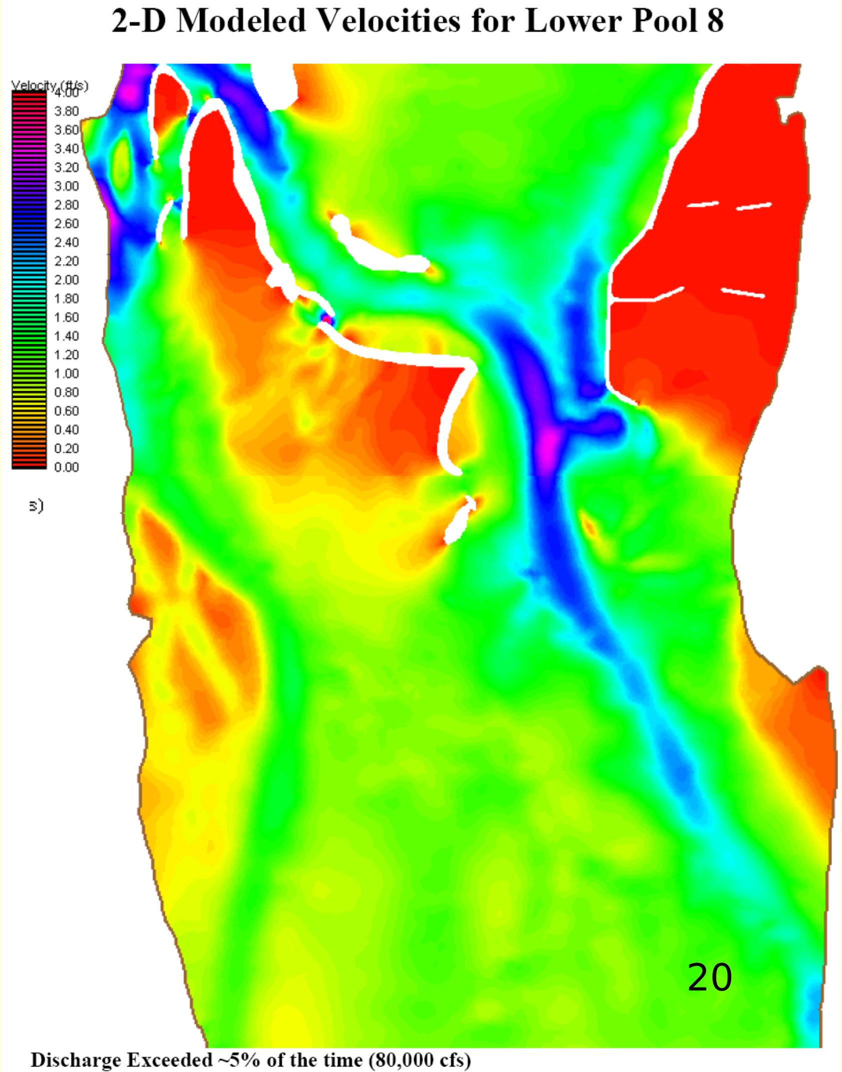
Varied Flow Conditions



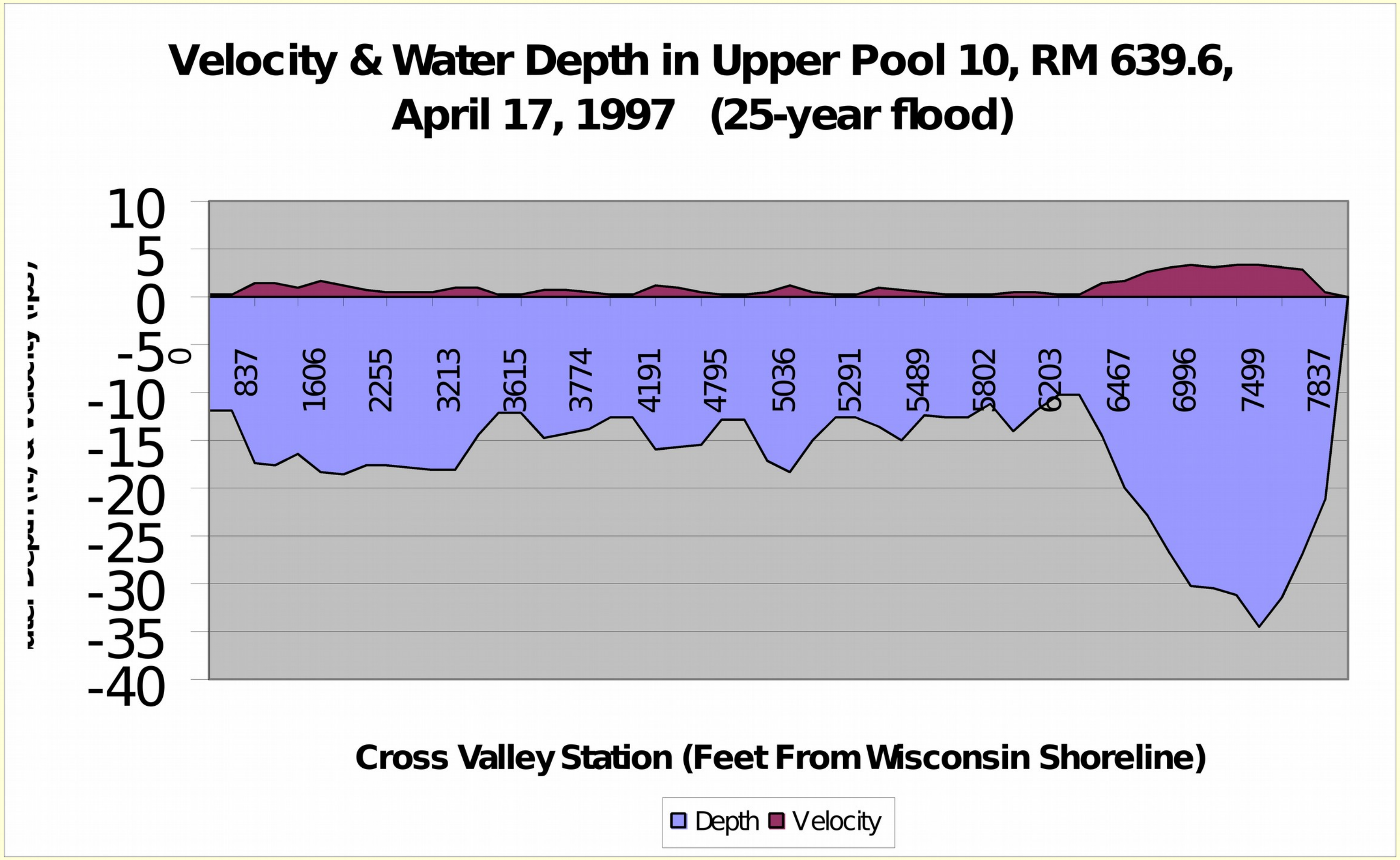
ow along these profiles is gradually varied (ie. the flow characteristics
ange slowly in the upstream to downstream direction). Right at the
rupt drop in the lower profile however the flow characteristics change vary fast.
is is known as rapidly varied flow

Change in modeled velocity with space and discharge





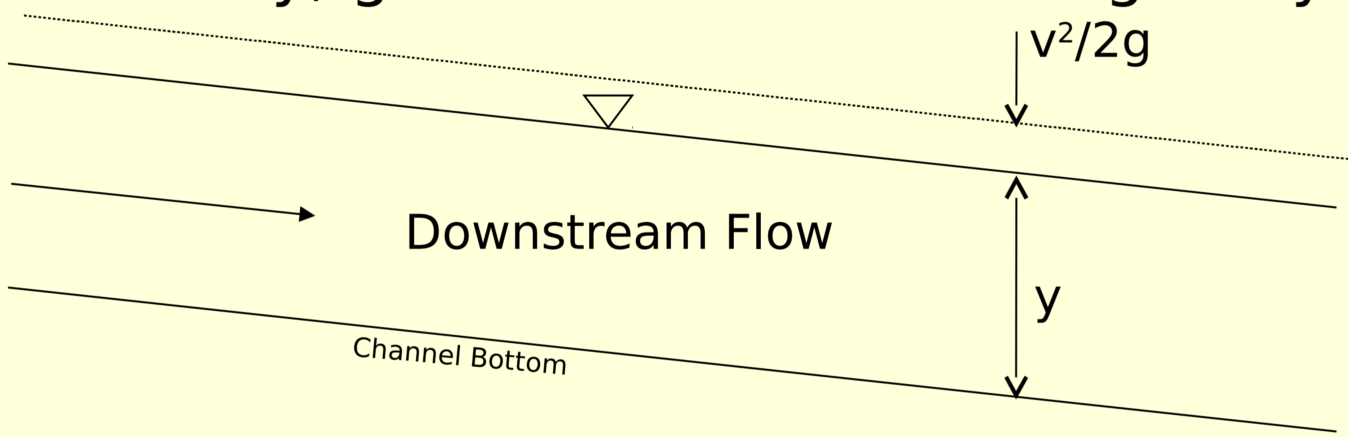
Change in Velocity Across River Valley During a Flood



Specific Energy (Open Channels)

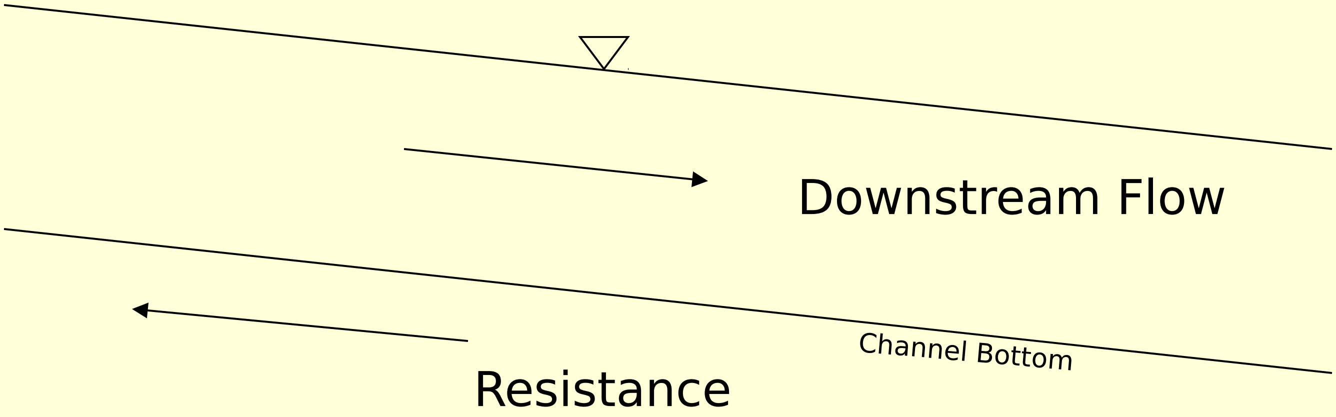
- For open channels, the specific energy can be defined as

  $E = y + v^2/2g$, where y is the depth of water above the channel bed, v is the flow velocity, g is the acceleration of gravity.

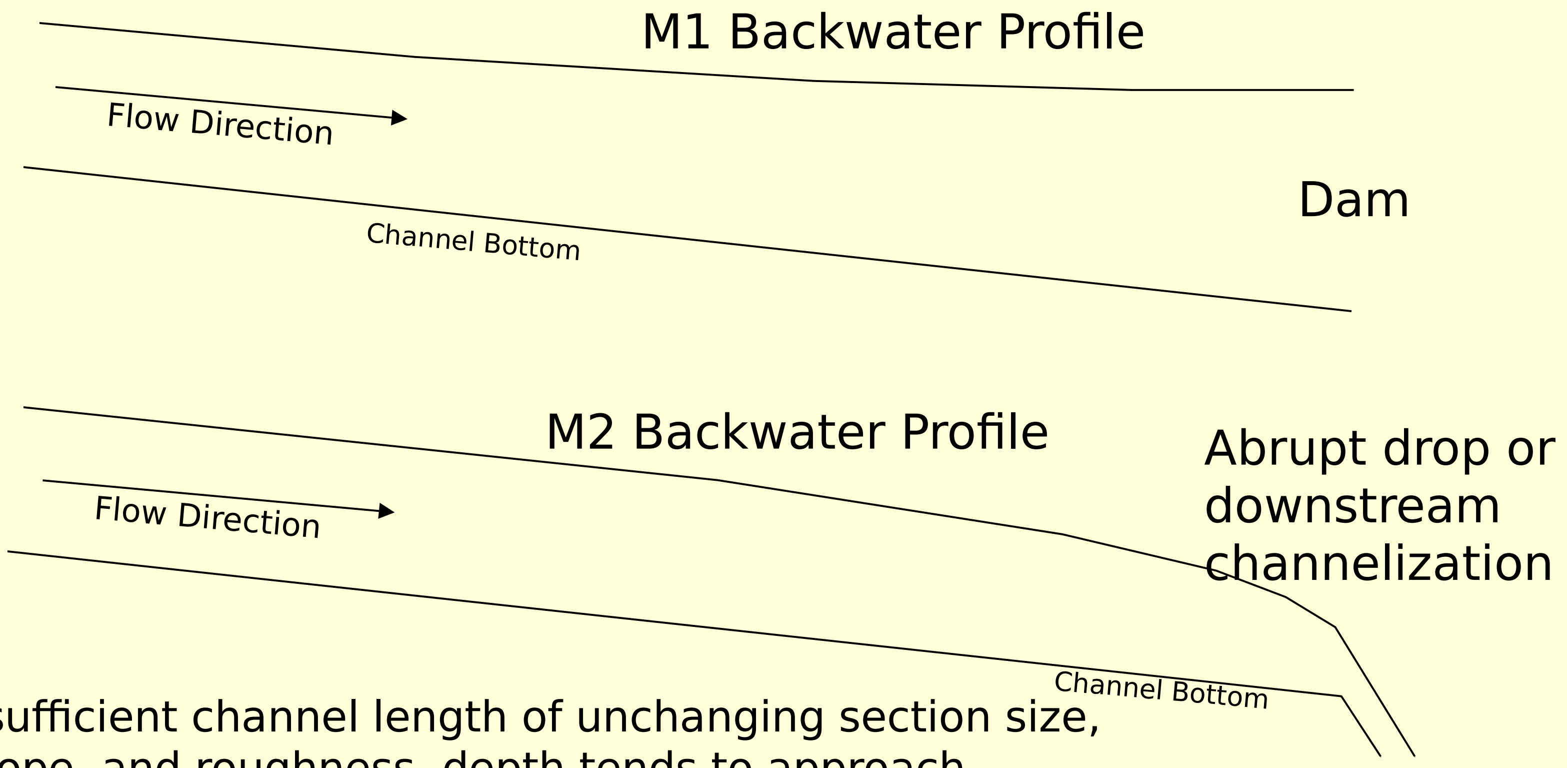


Normal Depth

- the depth for which available energy and energy expended are in balance



Seeking Normal Depth

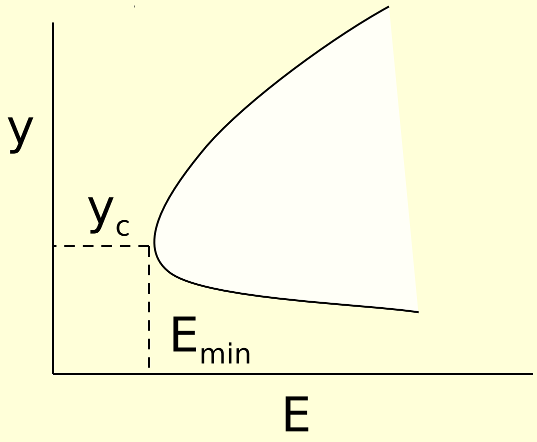


Given a sufficient channel length of unchanging section size, shape, slope, and roughness, depth tends to approach and/or maintain normal depth at some point upstream.

Critical Depth

- the depth at which energy is the minimum possible for an open channel cross section of a given size and shape and a given flow
- the VALUE of critical depth does not depend on roughness or slope, (only on discharge)

$$y_c = (q^2/g)^{1/3} \text{ (Rectangular Channels)}$$



Open Channel Flow Regimes

- Subcritical Flow:
  - is deeper and slower than critical flow
  - this is what you usually see in rivers.
  - relatively slow moving

- Supercritical Flow:
  - is shallower and faster than critical flow
  - this is what you see in steep channels (rapids or flow over a dam)
  - fast moving

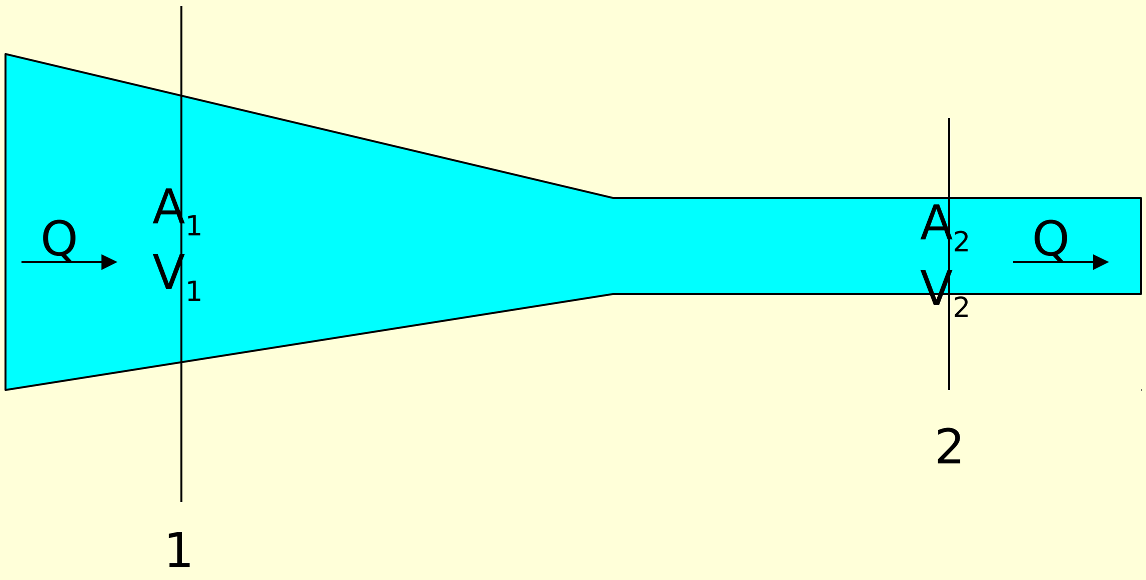
Open Channel Flow Regimes

- Hydraulic jumps occur when there is a transition from supercritical to subcritical flow

Continuity Equation

$$Q = V_1 A_1 = V_2 A_2$$

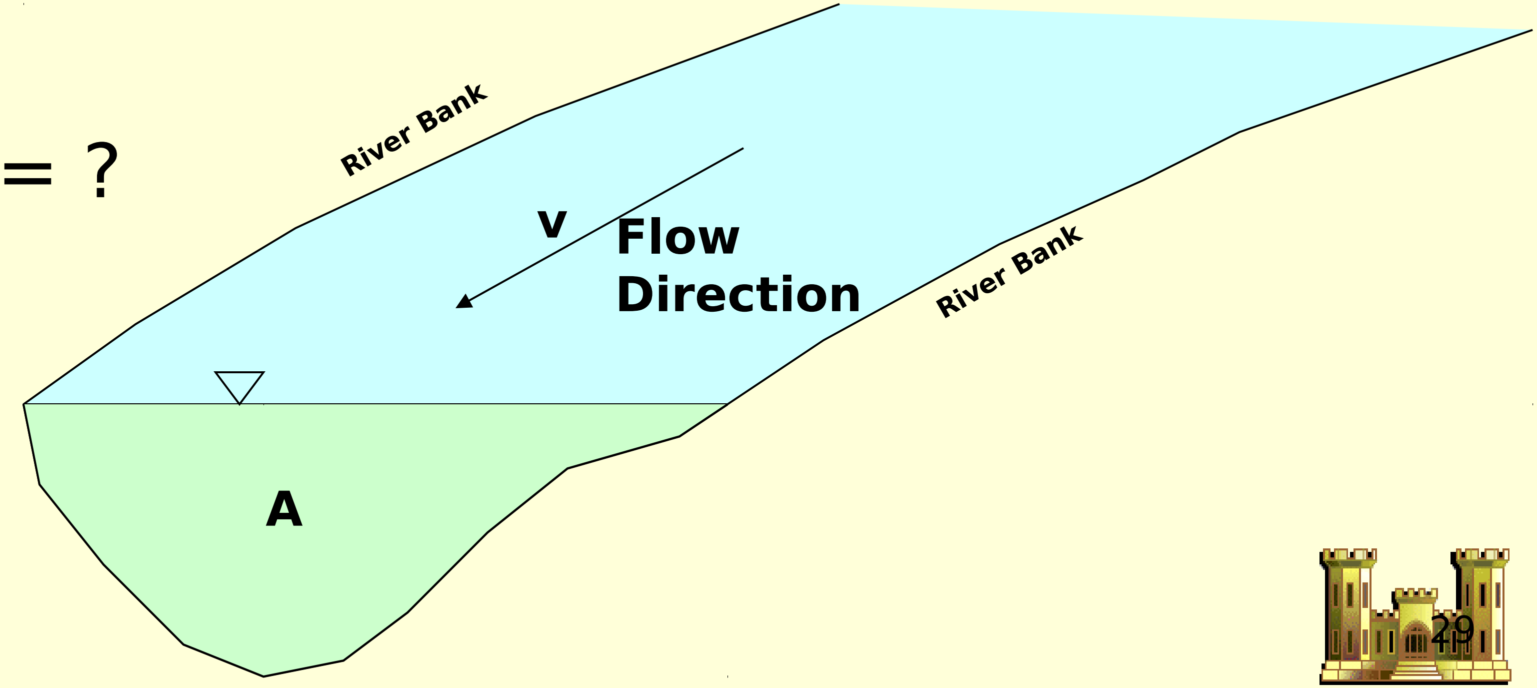
(Flow = Velocity X Area)



How do you calculate velocity

- What are some drivers (or parameters) that affect the speed that water moves at?
- What would a basic relationship look like?

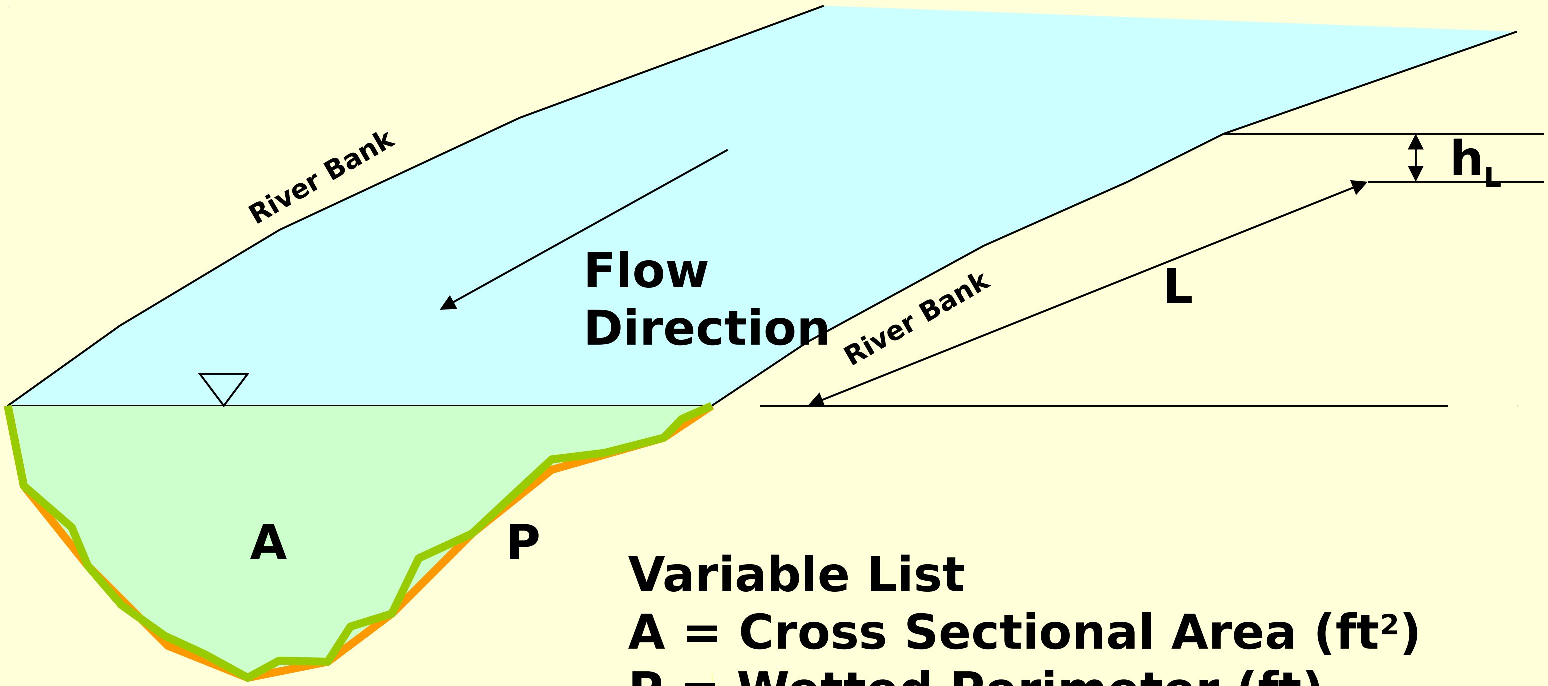
v = ?



Mannings Equation (English Units)

$v = 1.49R^{2/3} s^{1/2} / n$

$Q = 1.49AR^{2/3} s^{1/2} / n$



Variable List

A = Cross Sectional Area (ft^2)

P = Wetted Perimeter (ft)

R = A/P = Hydraulic Radius (ft)

n = boundary roughness

Q = Discharge (ft^3/s)

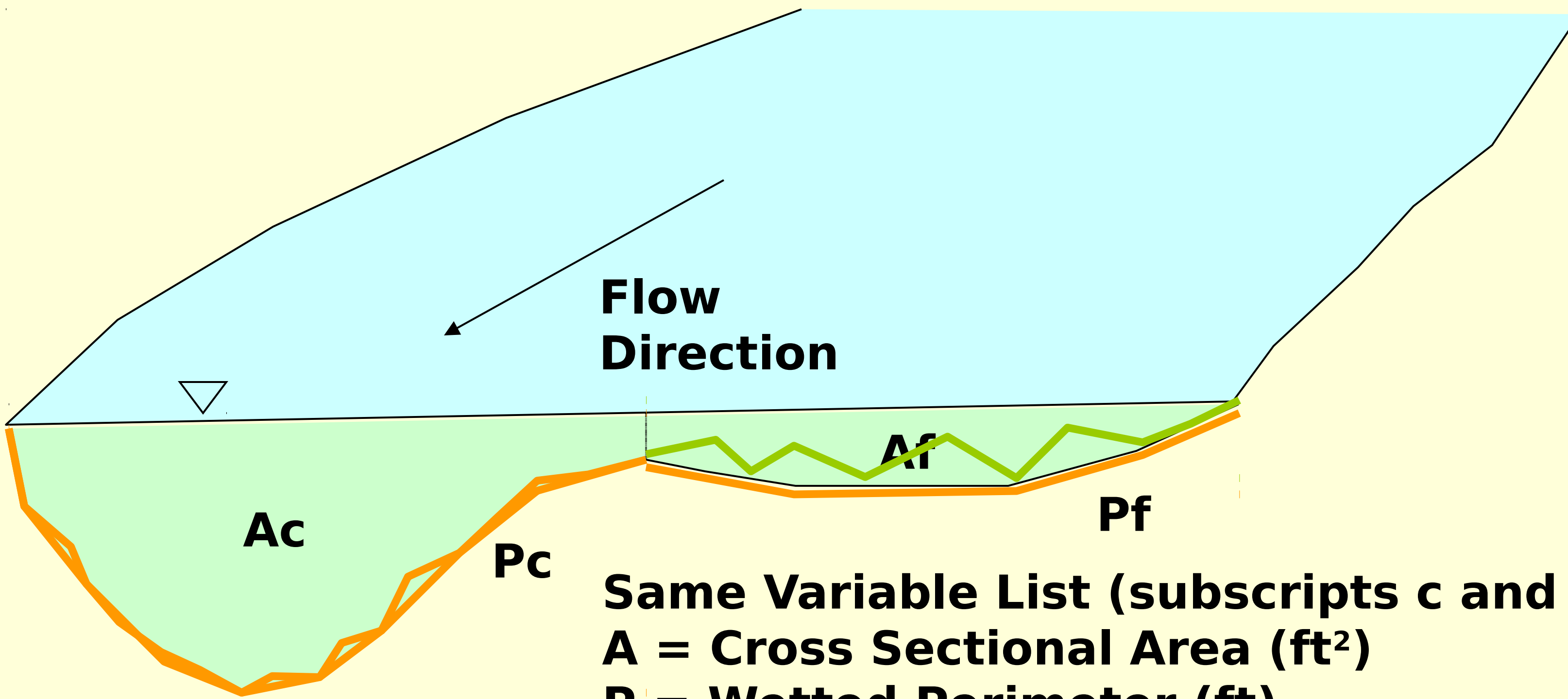
s = water surface slope = h_l/L

v = velocity (ft/s)

Mannings Equation with Floodplain Flow

Qtotal = Qchannel +Qfloodplain

$$Q_{total} = 1.49 A_c R_c^{2/3} s^{1/2} / n_c + 1.49 A_f R_f^{2/3} s^{1/2} / n_f$$



Same Variable List (subscripts c and f

A = Cross Sectional Area (ft²)

P = Wetted Perimeter (ft)

R = A/P = Hydraulic Radius (ft)

n = boundary roughness

Q = Discharge (ft³/s)

s = water surface slope

Cross Sections

Open Channel: Free surface varies with time affecting area, channel area, depth, roughness, and slope. The relationship between all these variables, usually makes open channel flow problems tougher to deal with.

Closed Conduits – The area of flow is known when it is flowing full – though closed conduit flow is often in the open channel mode (e.g. Many culverts, storm sewers)

Roughness (n-values)

Open Channel: roughness varies depending on water depth, substrate size, density of vegetation, ...

Closed Conduits – Roughness varies depending on material types, age, and condition of pipe.

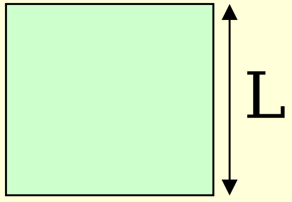
Hydraulic Radius, R

A/P where A = area (ft^2) and P = Perimeter (ft)

are Pipe Flowing Full

$A = L^2 \quad P = 4L \quad R = L^2/4L = L/4$

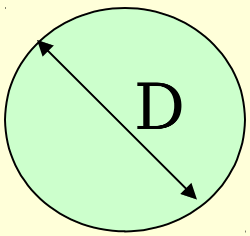
where L = side length (ft)



ular Pipe Flowing Full

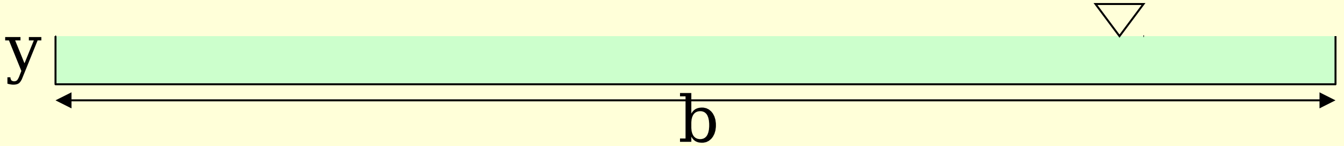
$$A = \pi D^2/4 \quad P = \pi D \quad R = \frac{\pi D^2/4}{\pi D} = D/4$$

where D = diameter (ft)



n channels where width is much greater than depth

$A = by \quad P = b+2y \quad R = by/(b+2y)$, but $2y << b$ so $R \approx y$



Slope, s

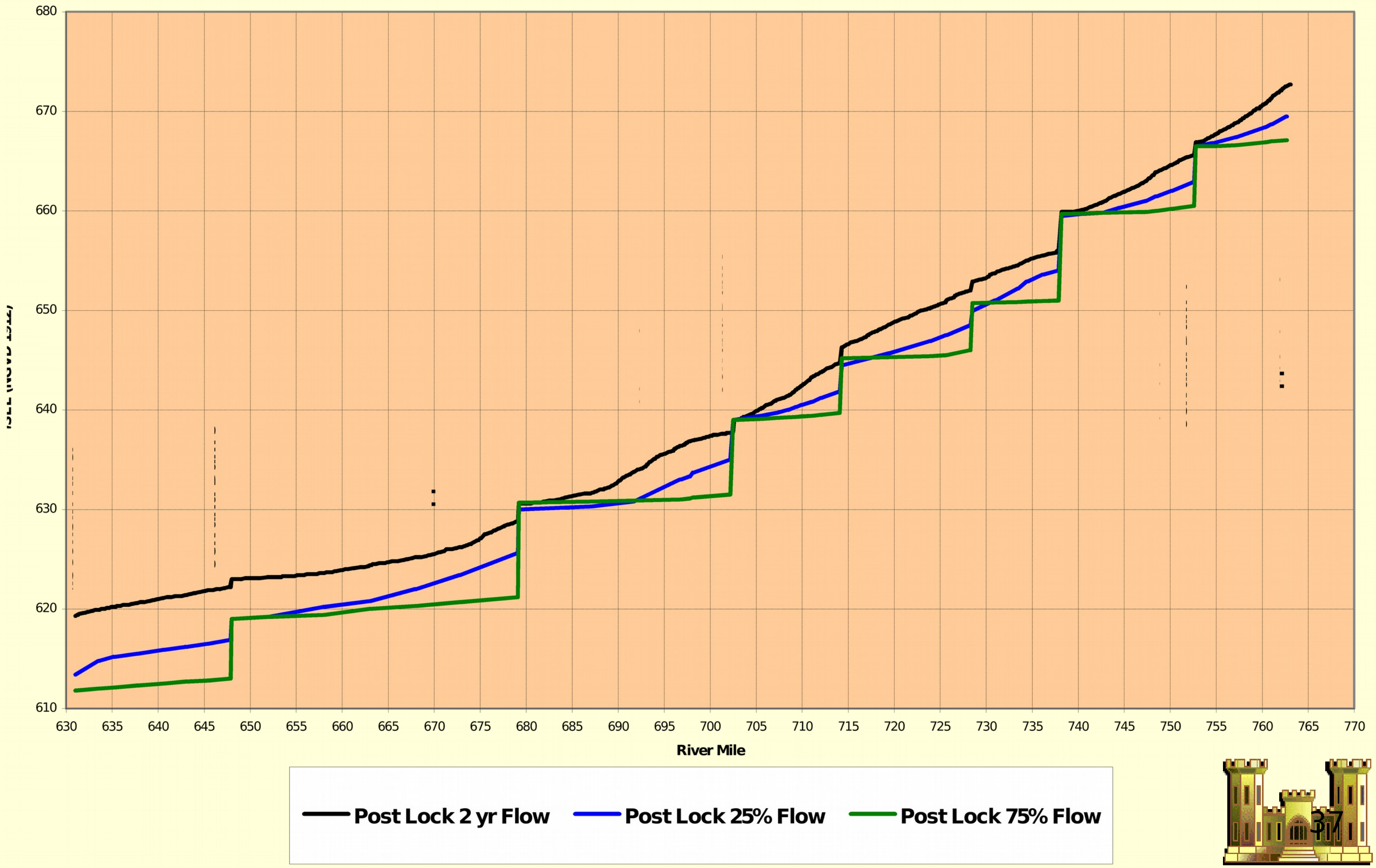
- this is the friction slope, i.e. the rate at which head (energy) is expended through friction per unit horizontal length of flow, ft/ft
- the physical slope of a pipe or the bed of an open channel may, or may not, happen to match the friction slope

Open Channel Flowlines

- a plot of water surface elevation over distance
- calculated by numerical models or by using existing gage data

-multiple flows: a family of flowlines

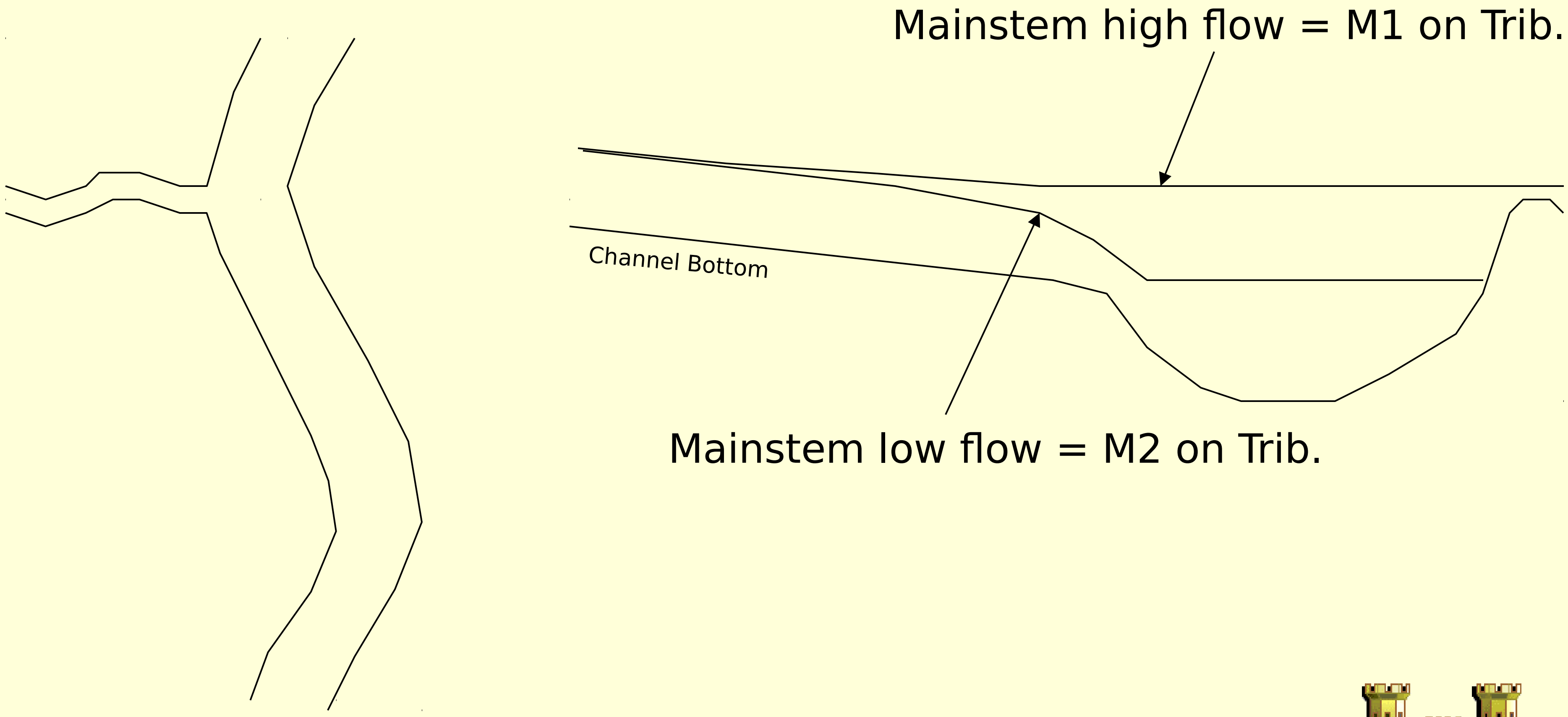
Family of Flow Lines



Changes That Tend to Raise a Flowline

- greater flow
- greater roughness
- lesser slope
- higher downstream water surface
- constricted area

Tributary-Main Stem Interaction



Bridge 6477

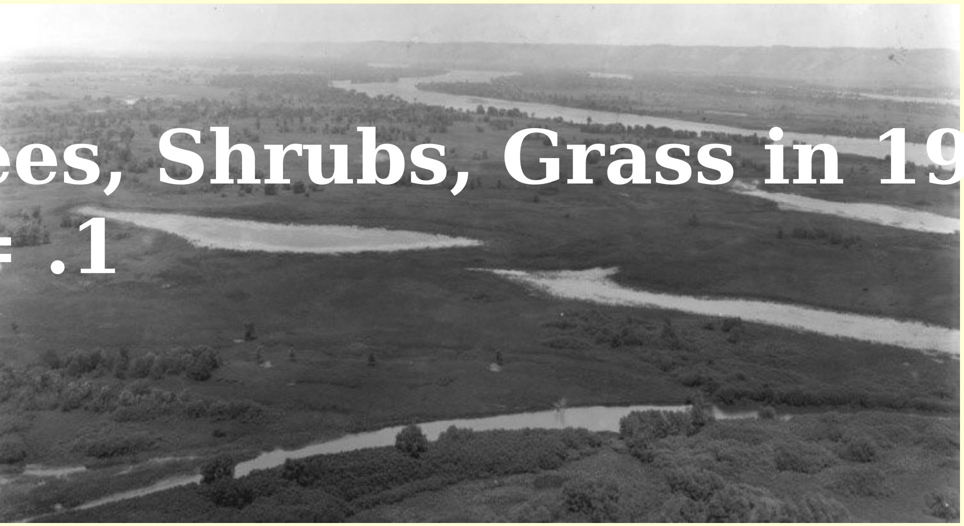
TH 75 over Wild Rice River
Flood 4/18/1997 Backwater of Red River

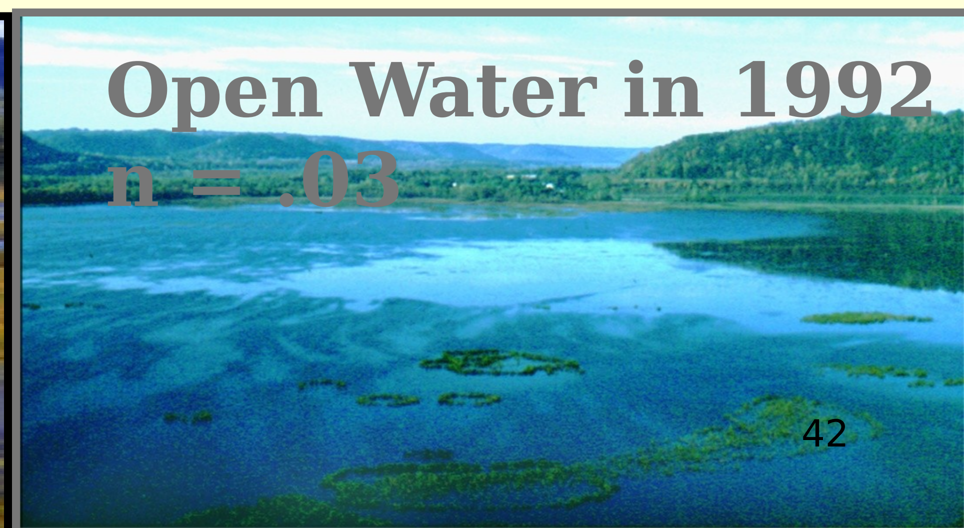
Bridge 6477

Flood 6/2002 over 500-year event

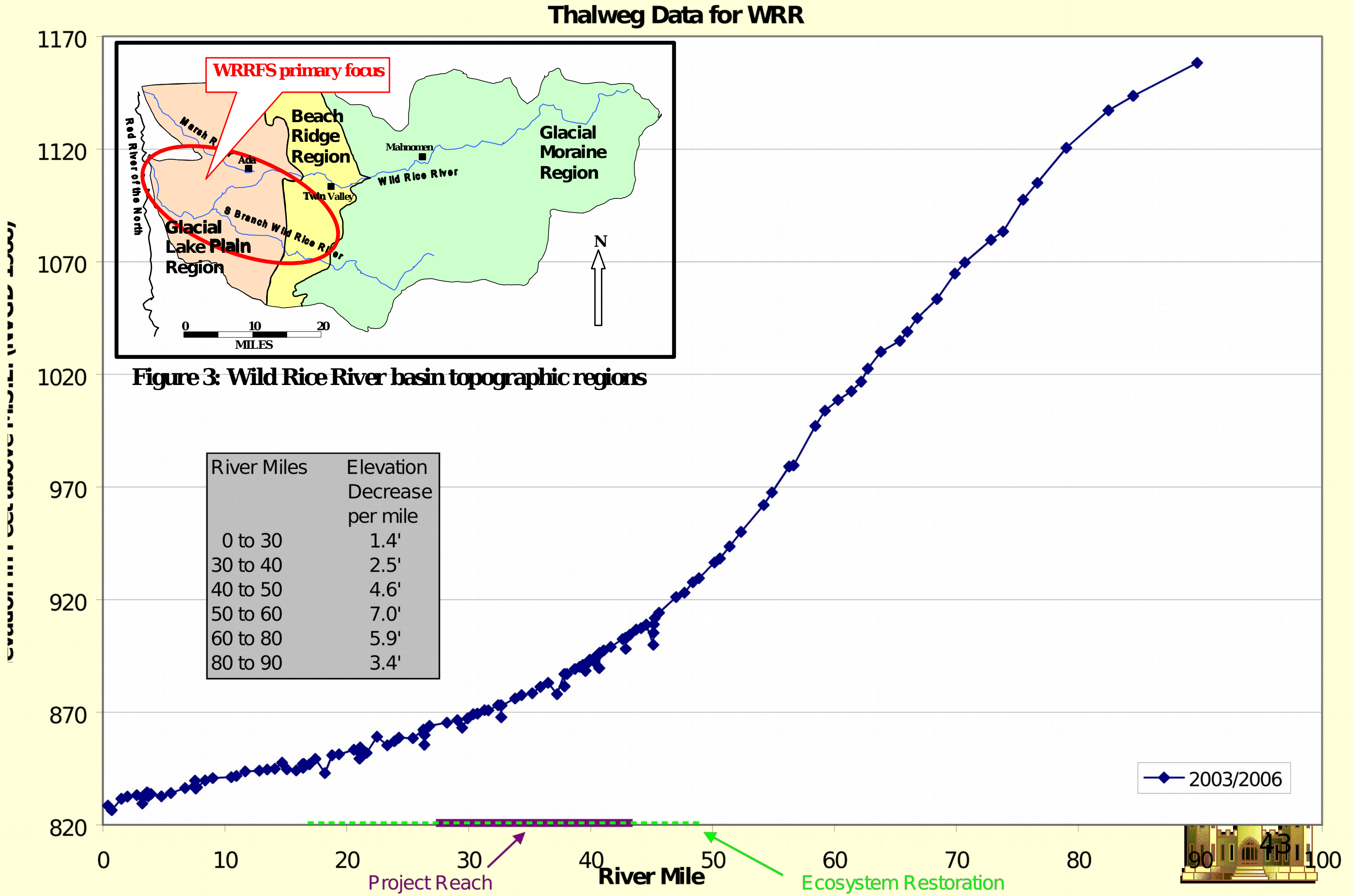
Change in floodplain features

and change in Manning's n with time due to dam construction, wind, river currents, ice



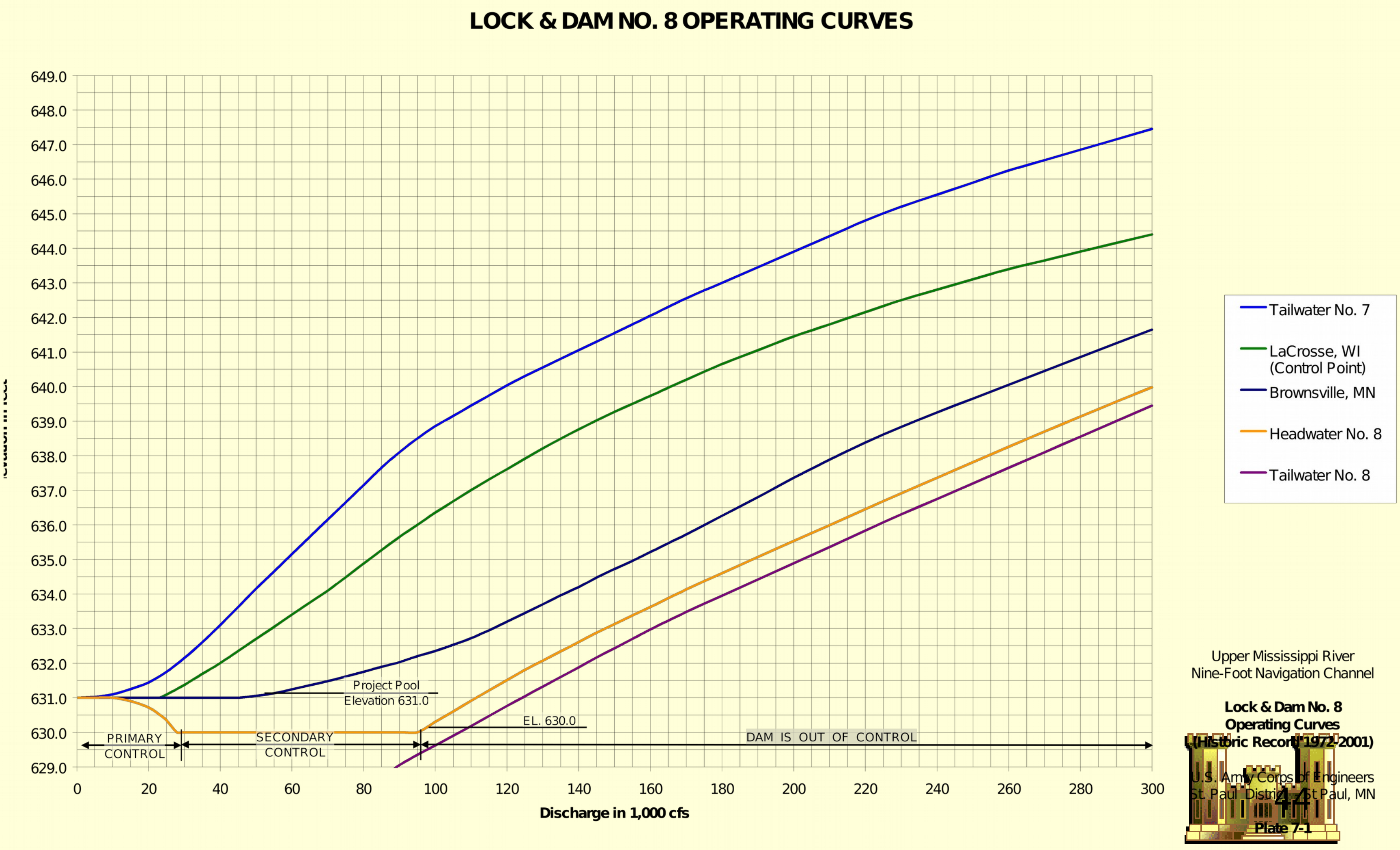


Slope of the lower 90 miles of the Wild Rice River, Western Minnesota



River Miles	Elevation Decrease per mile
0 to 30	1.4'
30 to 40	2.5'
40 to 50	4.6'
50 to 60	7.0'
60 to 80	5.9'
80 to 90	3.4'

Stage – Discharge Relationship

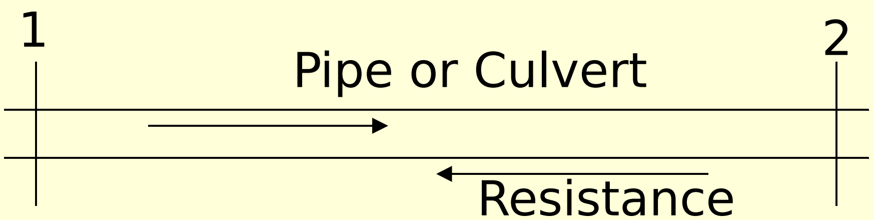


Closed Conduits or Pipes

Closed Conduits Flowing Full

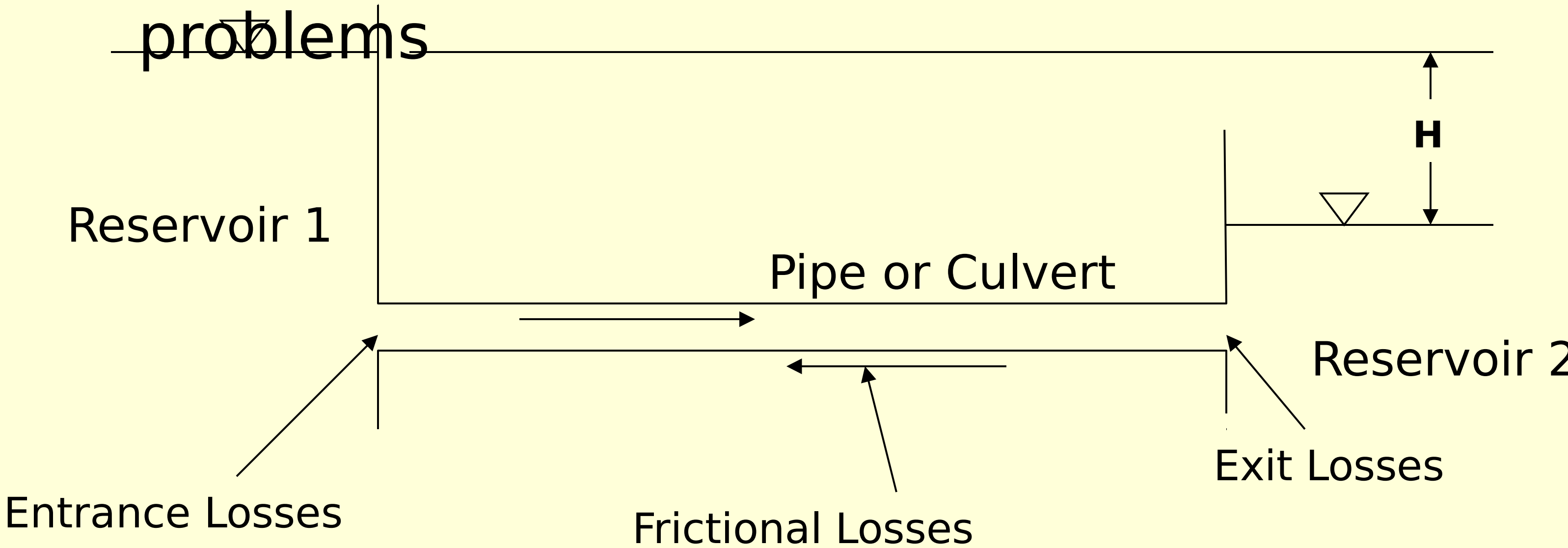
- Flow through a pipe can be calculated using Bernoulli's equation which relates available energy and pipe size to the resistance caused by friction within the pipe. In the diagram the energy is higher at section 1 than at section 2, resulting in flow from 1 to 2, but because of the roughness of the pipe walls, there is resistance.

$$p_1/\gamma + v_1^2/2g + z_1 = p_2/\gamma + v_2^2/2g + z_2 + h_{l1\text{-}2}$$



Closed Conduits Flowing Full

- Resistance can be divided into frictional loss, and minor losses caused by the entrance, gates, transitions, etc
- Mannings equation can be used (as opposed to the Bernoulli form of the equation) to solve problems

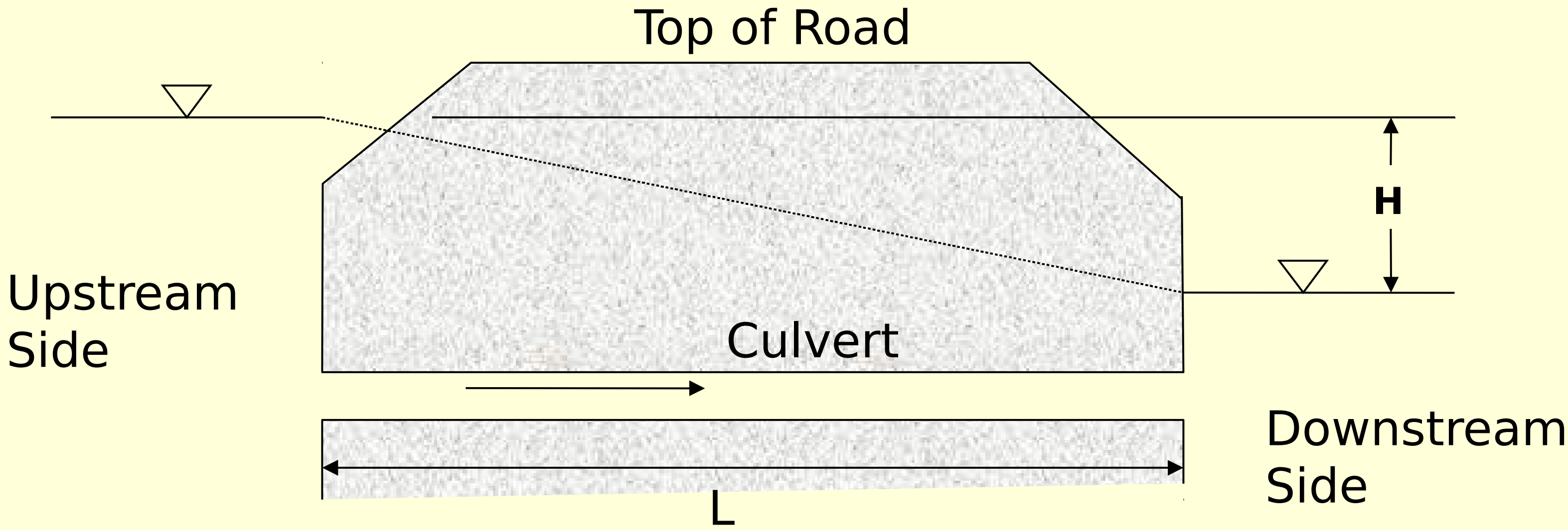


Closed Conduits Flowing Full

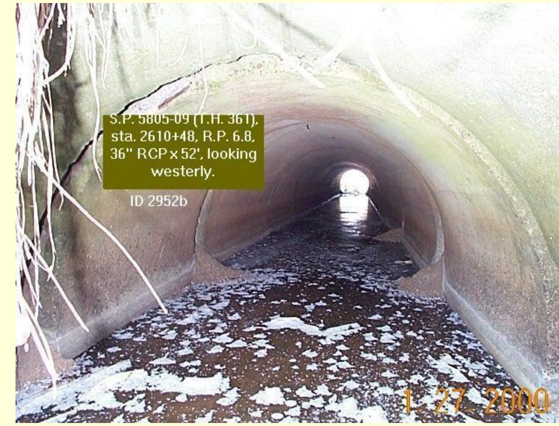
1. **Culvert area (A) is known**
2. **If flow is known, then velocity (v) is known, since Q = vA**
3. **With velocity known, the Manning equation can be used to calculate the hydraulic slope (s) to overcome friction in the pipe. v, R, and n are known, so solve for s.**

$$\mathbf{v = 1.49R^{2/3}s^{1/2}/n}$$

4. **Since s is equal to H/L, and L is known, then solve for H, or the difference in water surface from one side of the road to the other.**



Culvert Reality



Culvert Reality

Additional Hydraulic Topics

Open Channel
--The Weir

- doubling head more than doubles the flow. Look at the equation

$$Q = CBH^{3/2}$$

- Doubling head more than doubles the flow

$Q = CBH^{3/2}$

C = Constant

B = Width

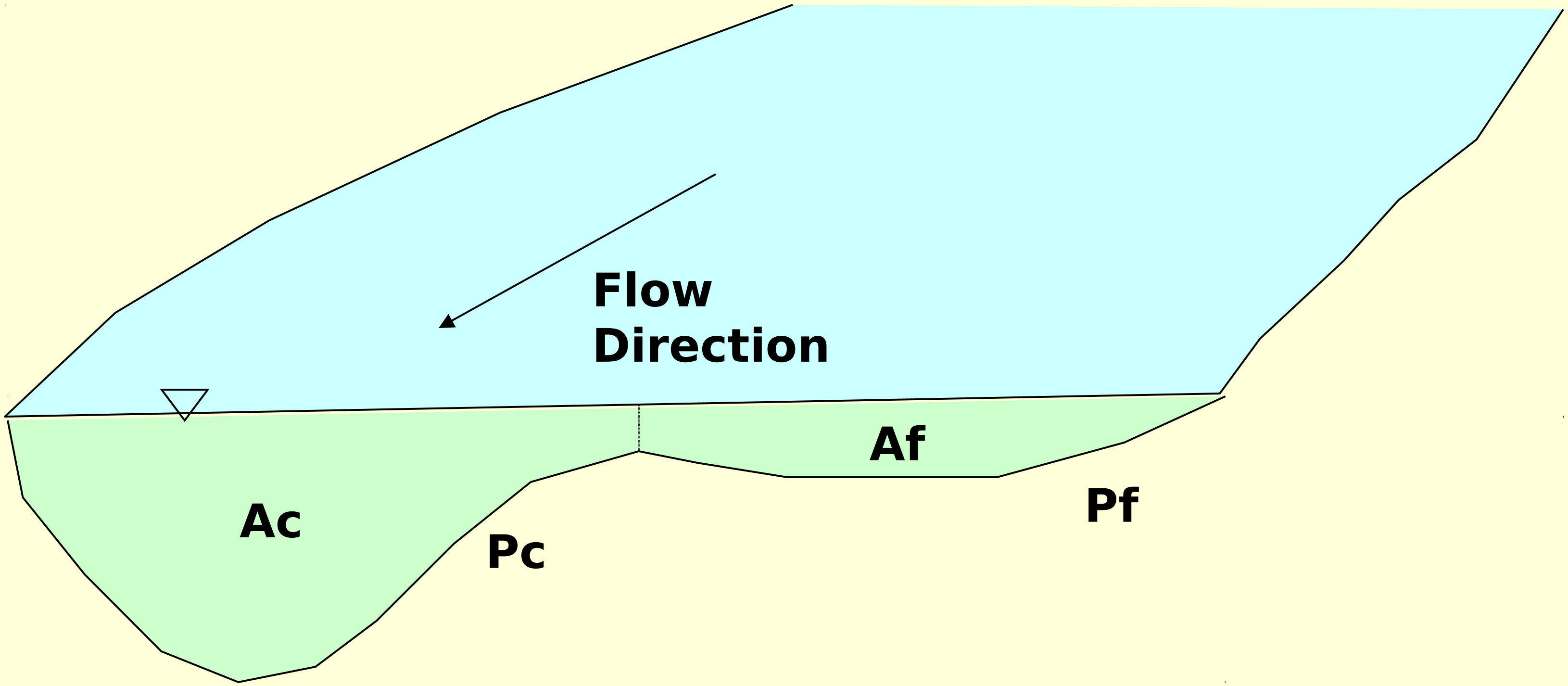
H = Head

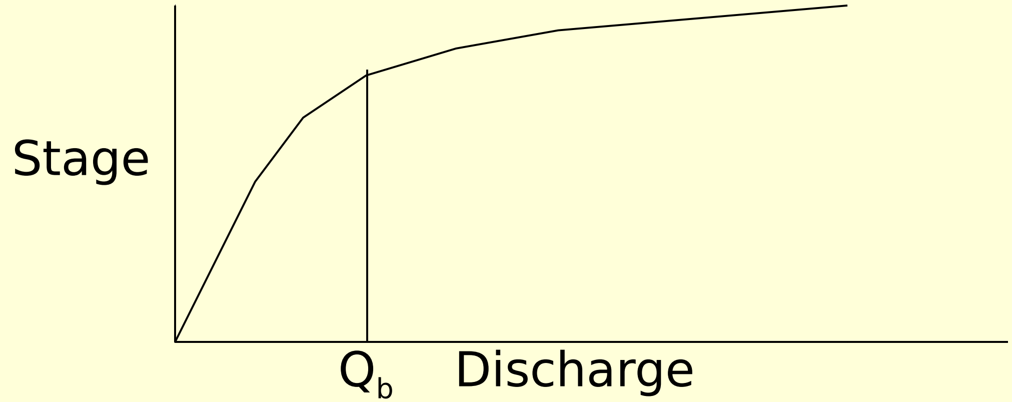
Closed Conduit Example --The Orifice

- head must be more than doubled to double the flow. Look at the equation

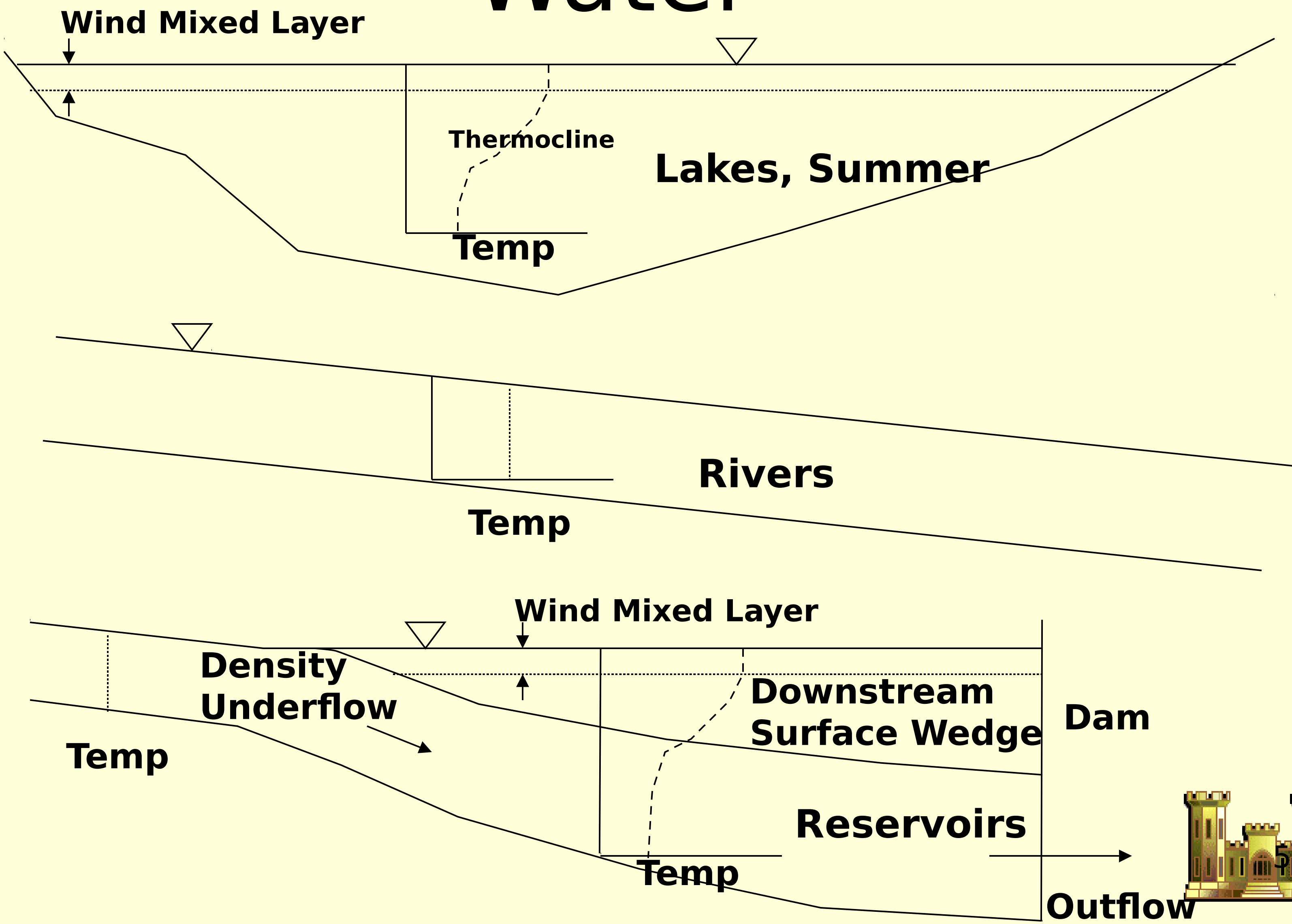
Orifice: $Q = CA(2gH)^{1/2}$

Bankfull Discharge





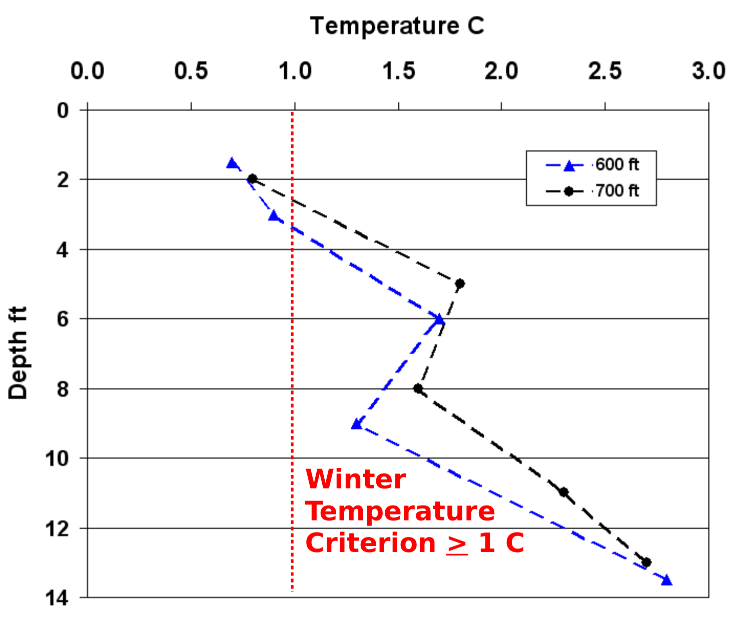
Temperature Effects on Water

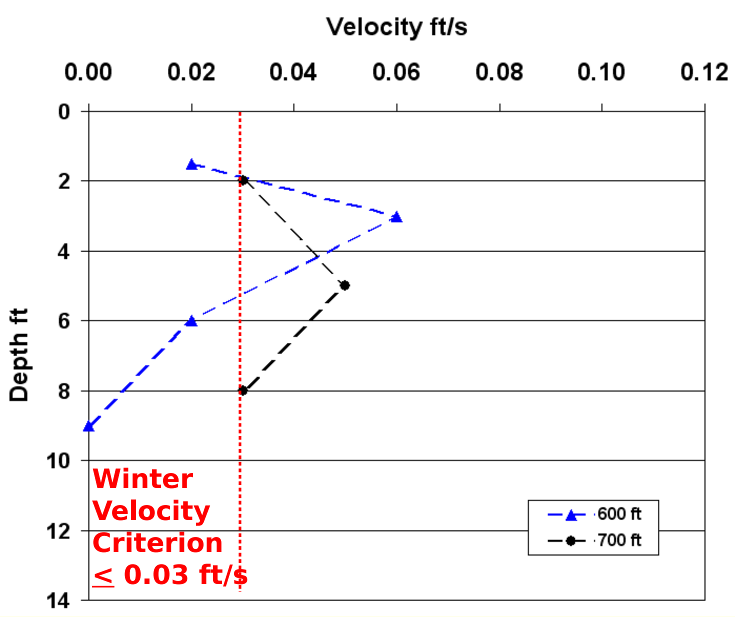


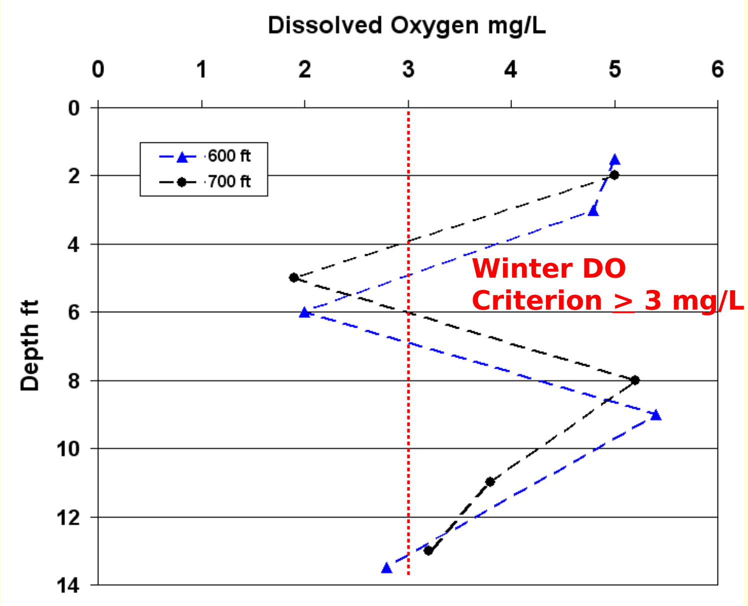
Ice Effects

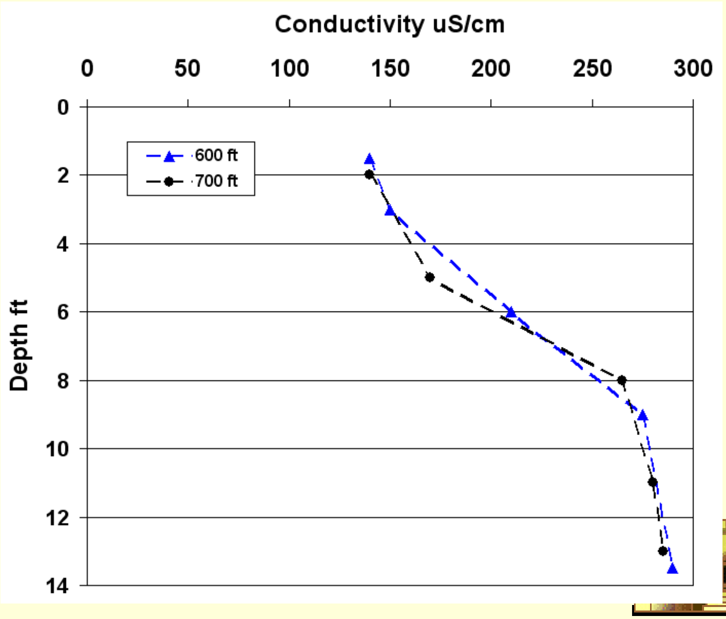
- Winter temperature profile – warmer water near the bottom. Ice is less dense than water (ice cubes float after all)
- Ice Damage – describe ice expansion-it happens in your freezer.
- Ice Jams
- Frazil Ice – super-cooled water
- Frozen subsurface water in soil reduces infiltration the next Spring
- Ice formation on steel structures,

Lake Onalaska Outside Dredge Cut 2/8/08









Ice Damaged Groin, Trempealeau National Wildlife Refuge

Root River Ice Jam


webpark.ru

Lock and Dam 2, Debris, 2001 Flood

Wind-Driven Wave Damage During a Flood

Groundwater/Surface Water Interaction

- Rivers re-charge groundwater table when river is high
- Groundwater recharges rivers when river is low
- Balance can be upset by dams, sediment deposition, groundwater pumping,…
- At reach scale (ie. study area is a small reach of a much larger river or stream), groundwater’s contribution to open channel flow is ignored.
- At a watershed scale, groundwater’s influence to open channel flow can be significant

Measuring Flow

- Velocity – Price, ADCP
- Discharge
- Stage
- Wind – waves
- Flow characteristics through a structure

Measurement Options

Measuremen t Options

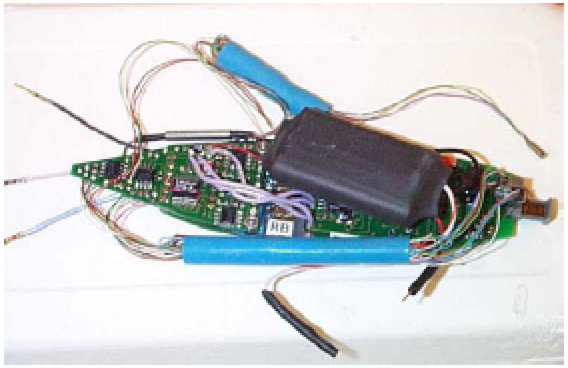


Figure 2.1. Pressure Transducer, Accelerometer, and Strain Gages in Sensor Fish Device

Figure 2.2. Initial Sensor Fish Device

Hydraulic Surveys

- Boat with dual 50 HP motors
- Fathometer
- GPS
- Laptop
- ADCP (Acoustic Doppler)
- Boat Safety Equipment and Training

~ The End ~